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Experimental Analysis and Feasibility Study of 1400 CC Diesel Engine Car Converted Into Hybrid Electric Vehicle by Using BLDC Hub Motors

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Abstract

New generation HEV (hybrid electric vehicles) are targeting for reducing exhaust gas pollution by operating in EV (electric vehicle) mode during the stop and go movement in thick traffic conditions at low engine rpm, but run on ICE (Internal Combustion engine) mode at cruising speed on highways. While new Hybrid car concepts are being developed internationally, existing Gasoline and Diesel powered conventional ICE vehicles will be guzzling unwanted pollutants for rest of their life, adding to the menace of global warming. To address the need for conservation of fuel and reducing production of harmful pollutants by millions of cars driven world over, an experimental research work was carried out in the field of conversion of existing diesel or petrol cars in to HEV. Main objective of the research is to reduce consumption of fossil fuel, for preserving it for future generation.

An existing 1400 CC Diesel car converted in to experimental HEV prototype has been tested in EV mode at reasonably steady speed on highway and conventional ICE mode, to measure the consumption of fuel to derive the optimum performance benefits. Test results show marked improvement in fuel consumption, when driven in EV mode (for distance covered with single charge) against ICE mode. Amount of fuel saving achieved by proposed HEV methodology deployed for conversion of existing vehicles contributes in equivalent reduction in total quantity of harmful exhaust emission pollutants.

The conversion process has been simplified, for implementation on existing cars and new model design of cars with engine capacity higher or lower than 1400 cc.

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Keywords: HEV; Conservation of fuel; Reduction in fuel consumption; Reduction in exhaust emission pollution

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1. Introduction

Recently, in the past decades Automotive Industries in the world realized the need for development of EV (Electric Vehicle) or HEV (Hybrid electric Vehicles) for two reasons.

A. Fast depleting fossil fuel capital resulting in steep hike in price of crude oil, due to enormous gap between dema nd and supply.
B. Achieving the stringent pollution standards enforced by the regulating authorities is becoming impossible or bei ng exorbitantly expensive to adopt newer technology. Due to which pricing of the new products being launched is becoming burden for manufacturers in order to meet the expectations of customers.

The reasons for EV's not getting popular amongst the users till to date are the low maximum speed in EV mode and unpredictable range that can be covered in a single charge, as well as the initial high cost of EV. Creating nationwide charging infrastructure has become a major national challenge. The new models of HEV are extremely complicated in construction. The integration and synchronization of electric motor drive with the ICE (Internal Combustion Engine) drive train becomes very complex, to match under all the operating conditions. Further, the increase in weight for the electric drive will again deteriorate the overall performance of the vehicle in ICE and/or EV mode. The additional cost is the monster always to be chased.

The HEV manufacturers have paid attention to reducing pollutants at low speed (low engine rpm) by operating on EV mode in stop and go (traffic congestion) condition but switching on to ICE mode on highways to achieve high running speed, beyond the speed capability of EV mode. Under such operating conditions, it is implausible dream to save fuel consumption and thus significant reduction in harmful pollutants will be farfetched hallucination. Merely because the ICE demands higher quantity of fuel for driving the vehicle at higher speeds rather than at low speed. Thus, quantity of fuel consumed by every car on highways is much higher in ICE mode (10 to 16 times higher as per the fuel delivery values of Fuel Injection Pump calibration), for the same no. of strokes at high speed as compared to low speed in city or at idling rpm (rotations per minute) of engine. The basic assertion of the work is derived from the driving cycle of vehicles on highways and city traffic (both distance covered wise or time duration wise) found to be 90:10 (approximation). Hence, the author has worked on the principle of driving the vehicle in ICE mode in traffic condition and EV mode on highways at reasonably high speed. Under such operating conditions, the current drawn by the motors is also lower, which provides the benefit of comparatively longer range as compared to driving in EV mode at low speed high torque requirement conditions. So the vehicle manufacturers need to relook at their strategy in the light of the global concerns for reduction in fuel consumption and exhaust emission pollution both and not in isolation. The regulating authorities also have to rethink the policy in terms of quantitative emission values per 100 km of vehicular running. Because, there is a limit to commercially viable solutions for reduction in pollutants through newer technology for achieving complete combustion of hydrocarbons, under all the operating conditions.

The author has tested 1400 cc diesel engine car converted into HEV prototype by using PM (permanent magnet) BLDC (brush less direct current) hub motors, as per the specifications of HEV reference Table.1, which may prove to be cost effective HEV solution. The objective is to achieve reduction in consumption of fuel and resulting reduction in harmful pollutants by converting millions of existing diesel and petrol driven cars, while it can be implemented on the new model cars as well. The methodology proposed by the author is expected to result in phenomenal saving of fuel to derive effective reduction in harmful pollutants due to the saving of fuel unused while driving in EV mode. The process of conversion is explained in detail.

Table 1. HEV Specifications V/s Conventional ICE vehicles

Parameters	Conventional ICE Vehicle	HEV after Conversion
Engine Peak Power	52 PS @ 5000	52PS
Engine Max. Torque, NM	85 @ 2500 rpm	85 @ 2500 rpm
Peak Power of Motor, PM BLDC	-	2+2 = 4 kw
Peak Torque of Motor, NM	-	15.37 X 2 = 30.74

HEV Battery Pack, 4x12 V, Lead Acid type	-	150 Ah
Passenger Mass	150 Kg	150 Kg
Curb weight of vehicle	1050 Kg	1250 Kg
Total Test Mass	1200 Kg	1400 Kg

2. Process of Conversion of existing car into HEV

The step by step process followed for the conversion of conventional diesel engine car in to HEV includes disassembly, manufacturing of necessary components (to suit the design of the existing vehicle), incorporate the desired selection of bearings (having dynamic load carrying capacity in radial as well as axial direction) on the shaft, accommodate suitable brake disc and callipers and preparing sub-assembly of Motors on the suspension arm RH & LH for final assembly on the vehicle.

2.1 Disassembly of PM BLDC Motor:

A. Motor outer and inner covers.
B. Stator shaft with stator winding from the housing Rotor.
C. Motor stator shaft, with inner and outer bearings.

2.2 Design and Manufacturing:

A. Outer cover of motor to suit the standard wheel rim of the vehicle.
B. Inner cover of Motor to adopt the brake disc mounting.
C. Shaft suitable for mounting in the suspension arm and mounting of 6206 2RS bearing in the Inner Cover as well as 805945 double balls self aligning bearing in the outer cover.

2.3 Disassembly of axle from the vehicle:

A. Remove wheel rim and tire assembly.
B. Disconnect Hydraulic brake pipes for rear brakes and Remove Drum brake assembly.
C. Dismantle lower mounting bolt of Rear Shock Absorbers and two lower arm fixing bolts at front end to dismantle suspension lower arm.
D. Remove axle shaft from lower arm by using 15 Tones capacity hydraulic press.

2.4 Sub-Assembly of PM BLDC Motor with axle on Suspension Arm:

A. Insert the stator shaft in the Suspension Arm (from inside) by using Hydraulic Press.
B. Assemble Inner cover sub assembly (along with 6206 2RS self aligning bearing and Disc Brake Disc), on to the stator shaft.
C. Slide stator winding assembly on to the stator shaft.
D. Slide Motor housing assembly (with permanent magnets) on to the Stator winding assembly.
E. Fit 805945 double ball self aligning bearing on the stator shaft by using fly press.
F. Assemble outer cover on the stator shaft.
G. Tighten fixing screws for Outer and Inner covers to the Rotor housing.

2.5 Final Assembly:

A. Assemble the Suspension Arm Assembly with PM BLDC Motor on the vehicle by fixing the front end mounting bolts.
B. Fix Shock Absorber lower mounting bolt.
C. Assemble Brake Callipers and connect Hydraulic pipes.

D. Fix up wheel rim with tires.
E. Do all the wiring harness connections for Motors, Controllers, and Accelerator Pedal for Electric Motors, Switches and Batteries.
F. Carryout proper bleeding of brakes. Top up the brake oil as necessary.

Fig. 1. Existing car with Brake drum assembly

Fig. 2. LH Hub Motor assembly with Brake Disc

Fig. 3. RH Hub Motor assembly with Brake Disc

Fig. 4. Test Set up

Fig. 5. Controllers mounted on dickey panel

Fig. 6. Conventional car Converted in to HEV

3. Vehicle Performance Testing

The driver and his driving habits are major contributing factors for fuel consumption performance of a vehicle. Hence, the author himself drove the car throughout the testing of conventional car before conversion as well as the HEV, to retain consistency of driving habits. The routes for testing were maintained the same, so that the gradients, turns, speed breakers and traffic conditions were comparable, during all the test runs. Tire pressures were maintained at 2.8 kg/cm^2 (for all four wheels).

The experimental test runs were carried out for several months on HEV for comparison of the Fuel consumption measurements, in ICE Mode and in EV mode. Thus, saving of fuel consumption in electric mode against the conventional mode could be calculated. The following parameters may have marginal impact directly or indirectly on vehicular performance (on the values of Fuel consumption of the vehicle). However, they were insignificant hence not considered for simplicity of understanding:

A. Difference in tropical conditions (e.g. atmospheric temperature and pressure) during different seasons.
B. Temperature rise in batteries due to continuous chemical reaction and ion exchange between cathode plates to a node plate.
C. Temperature rise inside the controllers due to management of highly fluctuating incessant current flow as per th e demand and supply. Because of the improvement in temperature control management and its effect on perfor mance in terms of output available to the drive wheels, through hub motors is applicable under best of the condi tions.
D. The Driver and co-driver were consistently the same and the marginal variation of weight for each of them, was not accounted, it being unimportant.
E. Regenerative braking system was not incorporated hence loss of energy during braking was not possible to be re covered.

Initially the tests were conducted to find the maximum speed that is achievable and the range (distance) in kilometres in EV mode that can be covered with the single charge of Battery. The distance range being purely the function of battery capacity and type of battery (weight of battery pack) etc., that was not the focus of the experiments, hence not included here.

Since the HEV is built on the existing vehicle, power train and body of vehicle remaining same, the road load for the HEV vehicle has increased by 200 Kg (due to the differential weight of two Hub Motors with brake disc fitted in place of rear brake drums: – 20 kg plus the weight of the battery pack: – 180 kg for 150 Ah Battery). The existing drive train (front engine – front wheel drive) is not disturbed at all.

As proposed by the author, vehicle is driven normally on ICE power in the city traffic and it is switched on to EV mode on highway, when adequate tractive force is reached by ICE mode. Even when the prototype vehicle is moving in EV mode, the vehicle ICE was required to run at engine idling speed to provide drive for power steering and compressor of car air conditioning system. In case the vehicle is without power steering and air conditioning, then engine can be shut down, while driving in EV mode (under such circumstances 100 % fuel saving can be achieved). The vehicle could negotiate normal long stretches of minor gradient in EV mode at reasonable running speed as well. If stretched for power from the energy source, it could also easily climb the normal over bridges. But the total current drawn during climbing of heavy gradient being high; it will reduce the maximum distance covered, on plain road, in single charge. Then the benefit of utilization of Motors with lower total power is defied.

The author has proposed to use total peak power capacity of Electric Motor to be much lower than the peak power of existing ICE of the vehicle to derive discrete advantages of comparatively higher specific power of Electric Motor, with lower power output requirement of Battery pack, with low specific energy. Also, the author is proposing to use the HEV on highways only and not in the city traffic, for the same reasons.The performance was tested mainly to determine saving of fuel consumption, on account of hybrid conversion.

The fuel savings obtained in the prototype HEV can be successfully expected as same as or very close to the results shown in this paper, on other such vehicles converted in to HEV also.

Table 2. Test results

Parameters	Conventional ICE Vehicle	HEV	% Saving of Fuel in EV mode V/s ICE
Fuel Consumption, Liters//100Km	4.65 4.83 5.05 5.12	2.29 2.62 2.19 1.97	50.8 45.8 56.6 61.5
Maximum Speed Achievable in HEV		62 km/hr	

4. Feasibility study

The fuel consumption reduction depends upon the road loads. In different driving conditions, fuel consumption measured at 1.97 liters per 100 km at 38.3 km/hr average speed and 27.5 km of distance could be covered, with 150 Ah Battery pack. Since the power to rpm curve for the motor is half parabola, higher the average vehicle speed with electric motors the lower the range of distance that can be covered with single charge of battery pack. Also at lower speeds, in electric mode the current drawn will be higher due to demand of high torque. Thus the range will be lowered. But, the fuel consumption in HEV mode varies between 1.97 to 2.62 Liters per 100 km, depending upon the traffic and driving conditions as compared to 4.65 to 5.12 liters per 100 km in ICE mode, as shown in Table. 2 The fuel consumption pattern in ICE mode before and after the conversion has been affected only marginally in ICE mode comparison. Hence, the performance of vehicle in ICE mode remains same, when the battery pack is not able to exceed the road load. The driver carries on with ICE mode without worrying about the range and chances of getting stranded due to battery energy exhausted.

Considering the test results of fuel consumption and the actual cost incurred the total cost and ROI (return of investment) for retro fitment expenses is worked out. The fluctuating rate of exchange for US Dollar v/s Rupee and the increasing prices of Diesel will nearly work out the same period for ROI, as given in the Table. 3

Table.3 Feasibility calculations

Breakeven Point and Return on Investment					
Item	Currency	Rate	Qty	Total	Total, INR 1$ = 55 INR
Motor, 48 V, PM BLDC	$	80	2	160	8800
Controller, 96 A	$	130	2	260	14300
Accelerator Control	$	10	1	10	550
Battery	INR	10000	4	40000	40000
Battery Charger	INR	3750	1	3750	3750
Voltmeter	INR	650	1	650	650
Suspension Arm	INR	2362	2	4724	4724
Brake Disc	INR	2023	2	4046	4046
Brake disc Screw	INR	37	12	444	444
Calipers	INR	1500	2	3000	3000
Brake pipes & hard ware set	INR	300	1	300	300
Axle shaft	INR	600	2	1200	1200
End Cover plate Inner	INR	750	2	1500	1500
End Cover Plate Outer	INR	750	2	1500	1500
End Cover fixing Screws	INR	10	16	160	160
Bearing Inner (6206 2RS1)	INR	342	2	684	684
Bearing outer (540749)	INR	750	2	1500	1500
Spacer inner	INR	75	2	150	150
Spacer Outer	INR	100	2	200	200
Axle Washer & Nut	INR	10	2	20	20
Shipment Charges	$	100	1	100	5500
Customs duty	INR	8745	1	8745	8745
Conversion Labour Charges	INR	3000	1	3000	3000
Profit for retrofitter	INR	6000	1	6000	6000

Grand Total, INR	110723
Km for ROI @ of Rs. 2.5 / Km	44289
ROI period months, @ 3000 Km per months	15
Rates considered are for Actual purchase cost for prototype. But the same may reduce at least by 30% for bulk buying from manufacturers directly. Charges for House hold electricity not considered.	

5. Results and Discussions

As such the popularity of new models of EV or HEV is yet to take off. It is very important to quickly develop cost effective, fuel saving measures to be implemented on new models as well as for retro fitment on the millions of existing vehicles. The author has provided such solution by using Hub Motors having lower peak power as compared to the ICE. So that as and when the high power requirement is experienced/desired by the driver the vehicle can be run on ICE, but it can be driven on battery pack / stored energy, to derive maximum fuel economy.

A. By using proposed lower power but high specific energy of Hub Motors, up to 61 % saving is achievable on the existing cars.
B. The existing driveline remains intact and does not need any modification. Hence, peak performance of the available drive line is retained / assured.
C. The total weight of the vehicle is increased by 200 kg approximately (depending upon the type/make and size of the set of batteries deployed). With lithium Ion or lithium Polymer/Phosphate batteries the weight will increase by 85 kg only. And the basic dimensions of vehicle after conversion in to hybrid electric vehicle e.g. wheel base and wheel track front remaining the same (no change), but wheel track rear being increased by 40 mm only, the difference in performance with respect to vehicle dynamics point of view is not expected to change. The increase in wheel track can also be rectified if volumes increase. The acceleration / deceleration and braking performance remains the same. Marginal increase in turning circle, by virtue of hybrid conversion is not at all noticeable.
D. The stability of the vehicle, ride and handling and manoeuvrability are totally unaffected because the same suspension front and rear (including suspension coil springs and shock absorbers) are utilized. The only change in un-sprung mass on the rear axle has increased by about 18 kg due to the difference in weight of brake drum being replaced with disc brake system for Hub Motors on both rear RH (Right hand) side wheel and rear LH (Left hand) side wheel. But the impact of minor increase in un-sprung mass is compensated by the increase in sprung mass of battery bank being placed inside the dickey (exactly on the centre line of rear axle – 180 kg for 4 Lead Acid batteries of 150 Ah).
E. Vehicular existing electrical system (12 V, with – ve earth) is not at all disturbed.
F. The complete vehicle braking system is utilized. Only the rear brake drums and brake back plates (RH and LH) are replaced with Disc brake is incorporated with brake callipers, without needing to modify or replace any hydraulic brake system components.
G. By introduction of hybrid electric propulsion system, along with existing front engine – front wheel drive line, the vehicle as such does not need any separate or additional instrumentation for the driver except that a digital or analogue volt meter is required, to indicate the hybrid battery pack voltage for monitoring the state of charge.
H. Minimum no. of parts required modifications as well as standard bearings and hardware parts were utilised, to reduce the costs.
I. Barring the inherent quality/tendency of electrical & electronics components, Better service life of the bearings, is ensured by using 6206 2RS bearing as additional bearing as inner bearing, in addition to 805945 double ball self aligning bearing (both are sealed bearings) in the newly designed motors.
J. The prototype HEV's power steering and air conditioning equipments are driven by the ICE. Hence, while the vehicle is driven in EV mode, ICE is running at idling rpm (rotations per min). However, on smaller vehicles if power steering is not available and air conditioning is not required, the vehicle engine can be shut down while the vehicle is being operated in pure EV mode. Thus 100 % saving of fuel can be achieved.Since; many of the vehicles will be equipped with power steering and air conditioning, the fuel consumed in running of ICE at idling rpm. If it can be utilized for on board charging of 48 V (HEV battery pack), it will revolutionize the HEV operations. The author's future work is in the same directions.

K. An appropriate torque capacity of PM BLDC hub motors can be selected for the particular vehicle for conversion in to HEV, for deriving optimum results. The advantage of hub motors is that the output is directly driving the wheels; hence the motors efficiency is the only loss.

6. Conclusions

A. The proposed method is expected to reduce the fuel consumption by 45 % to 61 %, when the HEV is operating in EV mode, with air conditioning and power steering operated by ICE at idling rpm. This results can be further improved if the high Ah, light weight batteries are utilized.
B. There is no worry about range of the battery, because the driver is able to drive in ICE mode immediately on noticing or feeling the state of charge is depleted. The vehicle is not stranded on road, due to exhausted battery pack energy.
C. It is possible to convert majority of the old cars with front engine front wheel drive vehicles in to Hybrid Electric car, without much of difficulty and at reasonable cost (Considering commercial viability for the consumer and the manufacturer both). Return on Investment for conversion in to HEV is 15 months only. Which is like to be lower (at least by 30 %) on effective commercialization.
D. This method of converting conventional car into HEV is very easy to implement in new models - introduced in future, by the vehicle manufacturers.The newly developed PM BLDC hub motors & shaft design provides necessary ease of conversion and serviceability.
E. Service life of ICE and driveline components will increase and maintenance cost of ICE and driveline assembly components will reduce. Because Electric Motors are directly driving the wheels in EV mode, all existing drive line components are lightly loaded. Thus tensile and shear stresses, maximum bending moments as well as fatigue, creep effect during continuous operations at high loading conditions, are avoided, during the period vehicle is being driven in Electric mode.

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